Cabin Environment and Perception of Cabin Air Quality Among Commercial Aircrew

TORSTEN LINDGREN, B.S., DAN NORBÄCK, PH.D.,
KJELL ANDERSSON, M.D., AND BO-GÖRAN DAMMSTRÖM, M.D.

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Objective: Our objective was to study the perception of cabin air quality (CAQ) and cabin environment (CE) among commercial cabin crew, and to measure different aspects of CAQ on intercontinental flights. ***Methods:*** A standardized questionnaire was mailed in February-March 1997 to all Stockholm-based aircrew on duty in a Scandinavian flight company (n = 1857), and office workers from the same company (n = 218). The answers were compared with an external reference group for the questionnaire (MM 040 NA). During this time, smoking was allowed on intercontinental flights, but not on other shorter flights. Smoking was prohibited on all flights after 1 September 1997. The participation rate was 81% (n = 1513) in the aircrew, and 77% (n = 168) in the office group. Air humidity, temperature, carbon dioxide (CO_2) and respirable dust were measured during intercontinental flights, during both smoking and non-smoking conditions. Statistical analysis was performed by multiple logistic regression analysis, keeping age, gender, smoking, current smoking, occupation, and perceived psychosocial work environment simultaneously in the model. ***Results:*** Air humidity was very low (mean 5%) during intercontinental flights. In most cases (97%) the CO_2 concentration was below 1000 ppm. The average concentration of respirable particles was 67 $\mu g \cdot m^{-3}$ during smoking conditions, and 4 $\mu g \cdot m^{-3}$ during non-smoking conditions. Complaints of draftiness, too high temperature, varying temperature, stuffy air, dry air, static electricity, noise, inadequate illumination, and dust were more common among aircrew as compared with office workers from the same company. Female crew had more complaints on too low temperature, dry air, and dust. Current smokers had less complaints on stuffy air and environmental tobacco smoke (ETS). Younger subjects and those with atopy (childhood eczema, allergy to tree or grass pollen, or furry animals) reported more complaints. Reports on work stress and lack of influence on working conditions were strongly related to perception of a poor cabin environment. Flight deck crew had more complaints about inadequate illumination and dust, but less complaints about other aspects of the cabin environment, as compared with flight attendants. Aircrew who had been on a flight the previous week, where smoking was allowed, had more complaints on dry air and ETS. ***Conclusion:*** Complaints about work environment seems to be more common among aircrew than office workers, particularly draft, stuffy air, dry air, static electricity, noise, inadequate illumination and dust. We could identify personal factors of importance, and certain conditions that could be improved, to achieve a better perception of the cabin environment. Important factors were work stress, lack of influence on the working conditions, and environmental tobacco smoke on some longer flights. The hygienic measurements in the cabin, performed only on intercontinental smoking flights, showed that air humidity is very low onboard, and tobacco-smoking onboard leads to significant pollution from respirable dust.

Keywords: aviation medicine, cabin air quality, environmental tobacco smoke (ETS), indoor air pollution, noise, occupational medicine, psychosocial work environment.

TRANSPORTATION BY AIR on a global basis is estimated to be growing at the rate of 5% per year (10), and worldwide more than 1 billion people are transported by aircraft annually (19). The cabin environment is characterized by a low relative air humidity, typically between 5–25% (19,21). Moreover, the cabin in commercial aircraft is densely populated, and exposure to environmental tobacco smoke (ETS) may occur if smoking is allowed (5–7,11,12,18,19). Earlier investigations on cabin air quality have focused on exposure to ozone during higher altitude flights in aircraft without ozone converters (4,13).

Complaints about poor cabin environment may comprise a sensation of dryness, stuffy air, odor, annoyance from environmental tobacco smoke (ETS), temperature discomfort, draft, noise, and static electricity. Earlier investigations have shown that such complaints are common in non-industrial workplaces, e.g., offices (26,28), schools (14,27), and hospitals (16). Complaints on the indoor air quality are often the starting-point of discussions about the medical relevance of indoor air quality, and demands for investigations into hygiene and environmental improvements.

Earlier studies in offices, hospitals and schools have shown that the perception of the indoor environment is related to various aspects of the physical environment (15), including ETS (32) and low humidity (14,16,17,24). In addition, complaints on poor indoor air quality are related to personal factors, and are more common among females (14,29), subjects with allergies (14,29,32), and related to reported psychosocial work climate

From the Department of Medical Sciences/Occupational and Environmental Medicine, Uppsala University, University Hospital, Uppsala, Sweden (T. Lindgren, D. Norbäck); Department of Occupational and Environmental Medicine, Örebro, Sweden (K. Anderson); and Department of Occupational Health and Aviation Medicine (HMS), Scandinavian Airlines System (SAS), Stockholm, Sweden (T. Lindgren, B-G. Dammström).

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Address reprint requests to: Torsten Lindgren, Occupational hygienist, Department of Occupational Health and Aviation Medicine (HMS), STOIM-O, Scandinavian Airlines System (SAS), S-195 87 Stockholm, Sweden; torsten.lindgren@sas.se

(14,16,29,32). Most studies (7,12,13) in aircraft have dealt with passenger comfort, and there are few larger studies available on health effects of cabin air quality on cabin crew (20).

The main aim of our study was to compare the perception of cabin air quality (CAQ) among commercial aircrew, with office workers in the same company, as well as an external reference group. The second aim was to identify personal, psychosocial, and occupational factors related to the perception of CAQ. The third aim was to measure the cabin climate and exposure to respirable particles in intercontinental flights, and differences in concentration of respirable dust during smoking and non-smoking conditions.

METHODS

The study is part of a larger project on cabin air quality and medical symptoms and respiratory disorders among aircrew at Scandinavian Airlines System (SAS). Detailed measurements of cabin air pollutants will be presented in a separate publication.

Questionnaire Study

A self-administered questionnaire was mailed in February-March 1997 to all Stockholm-based aircrew on duty in a Scandinavian flight company (n = 1857), and office workers from the same company (n = 218). The protocol of the study was approved by the Ethical Committee of the Medical Faculty of Uppsala University. The participation rate was 81% (n = 1513) in the aircrew, and 77% (n = 168) in the office group. The questionnaire contained questions from a standardized questionnaire (MM 040 NA) developed by the Department of Occupational and Environmental Medicine in Örebro (1,2). The questionnaire was previously validated and used in the Office Illness Study in northern Sweden (28). There were some additional questions from another questionnaire (31), as well as some specific questions for aircrew. The answers were compared with an external reference group for questionnaire MM 040 NA from nine "healthy" buildings. During the time of the questionnaire study, smoking was allowed on intercontinental flights, but not on other shorter flights.

The questionnaire contained 12 questions on subjective workplace air quality. A recall period of 3 mo was used for these questions. For each perceived climate variable, there were three alternatives to answer: "no, never," "yes, sometimes," and "yes, often" ("often" meaning every week). The prevalence of weekly complaints was calculated for each subjective climate variable. In the statistical analysis, weekly complaints were assigned value "1", and both "yes, sometimes", and "no, never" were assigned a zero value.

Assessment of Personal Factors

Information on age, gender, smoking habits, allergies, and atopy was obtained from the questionnaire. A history of atopy was defined as reporting allergy to tree or grass pollen, furry animals, or a history of eczema in childhood. A current smoker was defined as a subject who reported current smoking (>1 cigarette/day) in the questionnaire, or who had stopped smoking less than 6 mo ago. The questionnaire contained four questions covering different aspects of the psychosocial work conditions. The question "interesting/stimulation work" measured work satisfaction. The question "Too much work to do" covered stress due to excess of work. "Opportunity to influence on working condition" measured the degree of influence on working conditions, and the question "Do you get help from your colleagues when you have a problem at work" measured the degree of social support. The questions on psychosocial conditions, had four possible answers: "yes, often," "yes sometimes,","no, seldom," and "no, never." Each of the variables was assigned an index value from 0–3; "yes, often" was assigned "3"; "yes, sometimes" was assigned "2"; "no, seldom" was assigned "1"; and "no, never" were assigned a zero value. The valued were then divided by three, in order to get psychosocial variables ranging from 0–1.

In-Flight Measurements

Measurements were performed on six individual intercontinental aircraft of the same type (Boeing 767–300), with a total number of 190 seats. The smokers' seats in tourist class (rows 21–39), were located near the aft galley and smokers in the euroclass (rows 1–17) were located near the middle section.

The Boeing 767–300 has a total volume of 428 m^3 (9), and a ventilation system normally providing approximately 50% fresh air and 50% recirculated air to the passenger cabin. Normally, this should give an air exchange rate of about 7 turnovers per hour of fresh air in the cabin. Occasionally, the recirculation fans can be shut off by the pilot for shorter moments, resulting in a 100% fresh air supply and an twofold increase of supply of fresh air. The air flow rate on flight deck is about 60 turnovers per hour.

The fresh air is supplied by the engines in flight, and sterile while passing through heated zones in the engine (400°C). The air is conditioned by the air conditioning packs and ozone is removed by passing fresh air through a catalytic ozone converter. The cabin air circulation system utilizes a pre-filter for larger particles, a high efficiency particulate air filter (HEPA) capturing particles equal or greater than 0.3 μm with 99.99%

TABLE I. PERSONAL CHARACTERISTICS (%) FOR DIFFERENT OCCUPATIONAL GROUPS ONBOARD, AND REFERENTS.

Variable	Pilot N = 577	Purser N = 197	Steward N = 82	Flight Attendants N = 657	Office Workers N = 168	External Referents N = 319
Female	5	86	20	91	27	57
Current smokers	8	21	20	17	19	25
Hay fever	16	15	28	22	8	17

TABLE II. PREVALENCE (%) OF AT LEAST WEEKLY COMPLAINTS ON DIFFERENT ASPECTS OF CABIN ENVIRONMENT, REPORTED FOR THE PREVIOUS 3 MO.

Variable	Pilot N = 576	Purser N = 197	Steward N = 82	Flight Attendants N = 657	Office Workers N = 168	External Referents N = 319
Draftiness	18	26	27	25	2	4
Temperature too high	6	17	22	12	9	5
Varying temperature	20	23	35	30	16	5
Temperature too low	14	18	17	22	11	5
Stuffy air	10	36	49	58	14	10
Dry air	55	54	74	75	26	20
Unpleasant odor	1	10	13	16	5	5
Static electricity	2	45	50	46	10	4
Passive smoking	4	20	43	23	8	7
Noise	41	50	51	69	4	9
Inadequate light	30	22	18	17	8	8
Dust and dirt	41	39	32	45	6	10

efficiency, and a charcoal filter to remove volatile compounds. The air-conditioning system does not contain any air humidification devices. All commercial aircraft use pressurized cabins to provide a cabin atmosphere equivalent at 2000-2500 m above sea level. This cabin pressure is provided by bleeding air from the jet engine compressor stage.

Air humidity, temperature, respirable dust, and carbon dioxide (CO_2) were measured during cruise on intercontinental flights, 9 flights during smoking and 8 flights during non-smoking conditions. These measurements were performed during a 2-yr period (November 1995 to December 1997). Smoking onboard was allowed on all intercontinental flights until September 1, 1997, and was prohibited on all flights after this date. All aircraft were filled with passengers. The measurements were performed after take off, and before landing.

In-flight temperature and air humidity were recorded with a SWEMA logger 15 (SWEMA AB, Sweden), sampling 1-min average values. The logger was calibrated at the factory in connection with the investigation. Concentrations of respirable dust were measured by a direct reading instrument based on light scattering (Sibata P-5 h2, Sibata Scientific Technology Ltd, Japan), used in earlier indoor air investigations (27). Carbon dioxide concentration was measured by a direct reading infrared spectrometer (Rieken RI-411A, Rieken Keini, Japan), calibrated by standard gases containing known concentrations of CO_2. The signal from the dust monitor and the CO_2 meter were also recorded with the SWEMA logger, sampling 1-min average values. Noise was measured at two different flights, using a Norwegian Electronic 110 noise detector (class I), giving both equivalent noise levels in dB(A) and frequent analysis. The noise measurements were performed during cruising at flight deck, in forward galley, over wing, and in aft galley.

Statistical Methods

The influence of different factors on subjective indoor air quality was analyzed by multiple logistic regression,

TABLE III. REPORTED PSYCHOSOCIAL WORK ENVIRONMENT (%) FOR DIFFERENT OCCUPATIONAL GROUPS ONBOARD, AND OFFICE WORKERS.

Variable		Pilot N = 577%	Purser N = 197%	Steward N = 82%	Flight Attendants N = 657%	Office Workers N = 168%	External Referents N = 319%
Interesting/stimulating Work (work satisfaction)	Yes, often	81	79	61	61	85	80
	Yes, sometimes	15	19	35	37	14	19
	No, seldom	3	2	4	3	2	2
	No, never	<1	0	0	<1	0	0
Too much work to do (work stress)	Yes, often	3	21	24	13	34	30
	Yes, sometimes	39	70	64	69	60	55
	No, seldom	52	8	11	18	6	14
	No, never	6	<1	1	0	0	1
Opportunity to influence working conditions (work control)	Yes, often	10	7	3	3	33	33
	Yes, sometimes	30	41	37	26	59	49
	No, seldom	46	44	56	61	8	17
	No, never	15	8	5	11	<1	1
Degree of social support from colleagues	Yes, often	49	65	65	58	48	51
	Yes, sometimes	33	27	32	34	45	38
	No, seldom	12	7	3	7	6	9
	No, never	6	1	0	1	1	3

TABLE IV. ADJUSTED ODDS RATIOS (OR)* WITH 95% CONFIDENCE INTERVAL (95% CI) FOR RELATIONSHIPS BETWEEN AT LEAST WEEKLY COMPLAINTS ABOUT CABIN ENVIRONMENT, AND OCCUPATION (N = 1681).

	Occupation (Aircraft Crew Versus Office Workers)
Environmental Variable	Aircraft Crew OR (95% CI)
Draftiness	9.24 (3.29–25.90)***
Temperature too high	2.23 (1.19–4.18)*
Varying temperature	1.80 (1.10–2.96)*
Temperature too low	1.31 (0.73–2.34)
Stuffy air	3.26 (1.91–5.57)***
Dry air	5.68 (3.66–8.81)***
Unpleasant odor	1.54 (0.64–3.74)
Static electricity	4.76 (2.51–9.06)***
Passive smoking	1.81 (0.92–3.55)
Noise	30.23 (13.57–67.26)***
Inadequate illumination	4.10 (2.18–7.73)***
Dust and dirt	11.00 (5.55–21.78)***

*p < 0.05; **p < 0.01; ***p < 0.001.
*Calculated by multiple logistic regression analysis, including age, gender, atopy, current smoking, four psychosocial variables, and type of work (flight crew vs. office work) in the regression model.

by SPIDA statistical package (The Statistical laboratory, Macquaire University, Australia). Two types of statistical models were used. First, all cabin crew were grouped together, and compared with the internal reference group of office workers from the same company, adjusting for possible confounding of age, gender, atopy, current smoking, and the four psychosocial variables. In the next step, the statistical analysis was restricted to all aircraft crew, and type of occupation, age, gender, atopy, current smoking, and the four psychosocial variables simultaneously in the models. The colinearity diagnostics described in the SPIDA manual were applied (8). Initially, some colinearity problems were detected, but these were eliminated by centering the four psychosocial variables, by subtracting the mean value for each variable. Odds ratios (OR) with a 95% confidence interval (CI) was calculated. In all statistical analyses, two-tailed tests and 5% level of significance were used.

RESULTS

Among all participants, 53% were females, 14% were current smokers, 19% had hay fever, 9% used contact lenses, and mean age was 43 yr (SD = 8). Prevalence of personal factors in different occupations is given below (**Table I**). Complaints on noise, dustiness, stuffy air, dry air and static electricity were common in aircrew (**Table II**). When comparing the internal reference group of office workers from the same company with the external reference group, no major differences in complaints were observed. Reports on the psychosocial work environment in different occupations, including work satisfaction, work stress, influence on working conditions, and social support from colleagues is given in **Table III**.

Further statistical analysis was performed, applying multiple logistic regression analysis, adjusting for possible confounders; i.e., age, gender, atopy, current smoking, and psychosocial work conditions. Initially, all aircrew members were grouped together, and complaints on different aspects of the work environment were compared with the internal reference group of office workers (**Table IV**). The prevalence of most complaints, except too low temperature, unpleasant odor, and environmental tobacco smoke, was higher among aircrew members. The greatest differences were observed for complaints on noise, dust, draft, dry air, static electricity, inadequate illumination, and stuffy air.

In the next step, the statistical analysis was restricted to all cabin crewmembers, applying multiple logistic regression analysis, keeping both occupation, age, gender, atopy, current smoking, work satisfaction, work stress, influence on working conditions, and social support in the models (**Table V**). No major differences between males and females were observed, but females more often complained about too low temperature ($p <$

TABLE V. ADJUSTED ODDS RATIOS (OR)* WITH 95% CONFIDENCE INTERVAL (95% CI) FOR RELATIONSHIPS BETWEEN AT LEAST WEEKLY COMPLAINTS ABOUT CABIN ENVIRONMENT, AND PERSONAL FACTORS, IN THE TOTAL MATERIAL OF AIRCRAFT CREW (N = 1513).†

	Personal Factors			
Environmental Variable	Female Gender OR (95% CI)	Age[a] OR (95% CI)	Atopy OR (95% CI)	Current Smoker[b] OR (95% CI)
Draftiness	1.61 (1.00–2.60)	0.89 (0.73–1.07)	1.32 (1.00–1.73)*	0.98 (0.65–1.49)
Temperature too high	1.16 (0.68–1.97)	0.83 (0.65–1.06)	1.16 (0.84–1.61)	1.04 (0.66–1.66)
Varying temperature	1.04 (0.67–1.62)	0.91 (0.76–1.09)	1.50 (1.16–1.95)**	0.81 (0.54–1.21)
Temperature too low	2.17 (1.28–3.68)**	0.72 (0.58–0.90)**	1.00 (0.74–1.35)	0.78 (0.48–1.26)
Stuffy air	1.53 (1.00–2.33)	0.85 (0.70–1.04)	1.04 (0.79–1.37)	0.60 (0.41–0.88)*
Dry air	1.52 (1.00–2.31)*	0.80 (0.69–0.95)**	1.29 (0.99–1.66)	0.94 (0.65–1.35)
Unplesant odor	0.92 (0.48–1.76)	0.71 (0.51–0.98)*	1.69 (1.14–2.52)**	0.50 (0.25–1.00)
Static electricity	1.34 (0.86–2.09)	0.70 (0.56–0.88)**	1.30 (0.98–1.73)	1.13 (0.77–1.67)
Passive smoking	1.16 (0.67–1.98)	1.29 (1.01–1.64)*	1.02 (0.74–1.41)	0.18 (0.09–0.37)***
Noise	1.48 (0.99–2.21)	0.84 (0.71–0.99)*	1.36 (1.08–1.77)*	0.71 (0.50–1.02)
Inadequate illumination	1.17 (0.71–1.92)	1.16 (0.96–1.39)	1.18 (0.89–1.56)	1.32 (0.88–1.98)
Dust and dirt	1.57 (1.04–2.36)*	1.14 (0.97–1.33)	1.59 (1.25–2.02)***	0.89 (0.63–1.27)

*p < 0.05; **p < 0.01; ***p < 0.001.
†Calculated by multiple logistic regression analysis, including age, gender, atopy, current smoking, 4 psychosocial variables, and type of occupation onboard.
[a]Odds ratio calculated for a change of 10 years.
[b]Non-smoker = 0; smoker = 1.

TABLE VI. ADJUSTED ODDS RATIOS (OR)† WITH 95% CONFIDENCE INTERVAL (95% CI) FOR RELATIONSHIPS BETWEEN AT LEAST WEEKLY COMPLAINTS ON CABIN ENVIRONMENT, AND PERCEPTION OF PSYCHOSOCIAL WORK CLIMATE, IN THE TOTAL AIRCRAFT CREW STUDY GROUP. (N = 1513).†

	Psychosocial Work Conditions			
Environmental Variable	Work Satisfaction‡ OR (95% CI)	Stress Due to Excess of Work‡ OR (95% CI)	Work Control‡ OR (95% CI)	Social Support‡ OR (95% CI)
Draftiness	0.80 (0.38–1.68)	4.12 (2.09–8.11)***	0.32 (0.18–0.56)***	2.17 (1.24–3.79)**
Temperature too high	1.00 (0.40–2.48)	7.99 (3.45–18.53)***	1.79 (0.90–3.56)	0.47 (0.24–0.88)*
Varying temperature	1.39 (0.67–2.90)	5.28 (2.75–10.12)***	0.56 (0.33–0.95)*	1.30 (0.77–2.17)
Temperature too low	1.04 (0.46–2.35)	3.67 (1.76–7.67)**	0.46 (0.25–0.86)*	1.00 (0.56–1.76)
Stuffy air	0.58 (0.28–1.22)	5.41 (2.72–10.77)***	0.68 (0.39–1.20)	1.06 (0.62–1.83)
Dry air	0.68 (0.34–1.36)	4.60 (2.54–8.34)***	0.52 (0.32–0.84)**	0.86 (0.54–1.37)
Unpleasant odor	0.89 (0.31–2.58)	13.18 (4.35–39.93)***	0.21 (0.08–0.53)**	1.63 (0.68–3.90)
Static electricity	0.67 (0.31–1.46)	2.93 (1.40–6.16)**	1.01 (0.55–1.86)	1.48 (0.81–2.71)
Passive smoking	0.94 (0.39–2.26)	2.35 (1.02–5.40)*	0.56 (0.28–1.11)	2.09 (1.04–4.18)*
Noise	0.55 (0.28–1.08)	6.36 (3.53–11.46)***	0.63 (0.39–1.02)	0.86 (0.55–1.37)
Inadequate illumination	1.02 (0.47–2.21)	11.11 (5.62–21.97)***	0.46 (0.27–0.80)**	0.95 (0.56–1.59)
Dust and dirt	0.87 (0.46–1.66)	5.62 (3.16–9.98)***	0.54 (0.34–0.87)*	0.92 (0.59–1.44)

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
†Calculated by multiple logistic regression analysis, including age, gender, atopy, current smoking, four psychosocial variables, and type of occupation onboard.
‡Odds ratio was calculated for the extremes of this variable (0–1).

0.01), dry air ($p < 0.05$), and dust ($p < 0.05$). Younger subjects reported more complaints of too low temperature ($p < 0.01$), dry air ($p < 0.01$), unpleasant odor ($p < 0.05$), static electricity ($p < 0.01$), and noise ($p < 0.05$). Older subjects complained more about environmental tobacco smoke ($p < 0.05$). Atopy was one of the more significant personal factors with respect to subjective cabin air quality (CAQ). Subjects with atopy, defined as allergy to tree or grass pollen, furry animals, or a childhood history of eczema, more often complained of draftiness ($p < 0.05$), varying temperature ($p < 0.01$), unpleasant odor ($p < 0.01$), noise ($p < 0.05$), and dust ($p < 0.001$). For most types of complaints, there were no differences between smokers and non-smokers, but smokers complained less about stuffy air ($p < 0.05$), and ETS exposure ($p < 0.001$).

Reports of work stress and lack of influence on working conditions were related to perception of a poor cabin environment (**Table VI**). All types of complaints were strongly related to work stress because of excess work ($p < 0.001$), and many were related to lack of influence on working conditions. In contrast, there were no significant relationships between work satisfaction, and any type of complaints, and little and inconsistent influence of social support from colleagues.

When comparing complaints on CAQ between different occupations, the level of complaints among flight attendants (air hosts) was used as a reference values (**Table VII**). The same logistic regression models were used, adjusting for age, gender, atopy, smoking, and the four questions on psychosocial work conditions. No major differences were observed between cabin crew of different occupation, except for a higher occurrence of complaints on ETS among stewards ($p < 0.01$), and less complaints on stuffy air ($p < 0.001$), dry air ($p < 0.01$), and noise ($p < 0.01$) among pursers. In contrast, flight

TABLE VII. ADJUSTED ODDS RATIOS (OR)† WITH 95% CONFIDENCE INTERVAL (95% CI) FOR RELATIONSHIPS BETWEEN BETWEEN AT LEAST WEEKLY COMPLAINTS ON CABIN ENVIRONMENT, AND TYPE OF OCCUPATION ONBOARD, USING FLIGHT ATTENDANTS AS REFERENCE GROUP (N = 1513).†

	Type of Occupation Onboard			
Environmental Variable	Pilot OR (95% CI)	Steward OR (95% CI)	Purser OR (95% CI)	Flight Attendants OR (95% CI)
Draftiness	1.56 (0.92–2.65)	1.52 (0.78–2.96)	1.34 (0.87–2.08)	1
Temperature too high	0.33 (0.18–0.63)**	0.98 (0.47–2.03)	0.75 (0.45–1.25)	1
Varying temperature	0.93 (0.57–1.52)	1.36 (0.73–2.53)	0.79 (0.51–1.22)	1
Temperature too low	1.58 (0.89–2.79)	1.15 (0.53–2.50)	1.20 (0.74–1.95)	1
Stuffy air	0.14 (0.08–0.22)***	0.91 (0.50–1.67)	0.46 (0.30–0.68)***	1
Dry air	0.86 (0.54–1.35)	1.21 (0.63–2.34)	0.53 (0.36–0.79)**	1
Unpleasant odor	0.10 (0.03–0.26)***	0.78 (0.33–1.87)	0.82 (0.43–1.59)	1
Static electricity	0.04 (0.02–0.08)***	1.31 (0.71–2.40)	1.50 (0.99–2.28)	1
Passive smoking	0.17 (0.09–0.34)***	2.76 (1.41–5.40)**	0.62 (0.38–1.02)	1
Noise	0.64 (0.41–0.98)*	0.59 (0.33–1.08)	0.54 (0.36–0.79)**	1
nadequate illumination	3.93 (2.29–6.74)***	0.87 (0.40–1.91)	1.19 (0.76–1.87)	1
Dust and dirt	1.82 (1.17–2.83)**	0.74 (0.40–1.37)	0.71 (0.49–1.04)	1

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.
†Calculated by multiple logistic regression analysis, including age, gender, atopy, current smoking, four psychosocial variables, and type of occupation onboard.

TABLE VIII. ADJUSTED ODDS RATIOS (OR)[a] WITH 95% CONFIDENCE INTERVAL (95% CI) FOR RELATIONSHIPS BETWEEN SUBJECTIVE CABIN AIR QUALITY, AND WORK ON SMOKING FLIGHTS DURING THE LAST 7 DAYS (N = 1513).*

Climate Variable	Work on Smoke Flight Last 7 Days OR (95% CI)
Stuffy air	1.31 (0.99–1.73)
Dry air	1.32 (1.02–1.70)*
Unpleasant odor	1.40 (0.92–2.14)
Passive smoking	4.02 (2.90–5.59)***

*$p < 0.05$; ***$p < 0.001$.
[a]Calculated by multiple logistic regression analysis, including age, gender, atopy, current smoking, four psychosocial variables, and type of occupation onboard.

deck crew had significantly less complaints on many aspects of CAQ ($p < 0.001$). Flight deck crew, however, reported more complaints on inadequate illumination ($p < 0.001$) and dust ($p < 0.01$), as compared with flight attendants.

The questions on CAQ were addressing the conditions during the last 3 mo. For practical reasons, information on work on particular flights, and flight numbers, could only be achieved for the week prior to answering the questionnaire. Based on flight number, the flights were classified as either smoking flights or non-smoking flights. Aircrew that had been on a smoking flight the previous week, reported significantly more complaints on dry air ($p < 0.05$) and ETS ($p < 0.001$) (**Table VIII**).

The hygienic measurements, performed on 17 flights, showed that mean temperature onboard was 22.7°C, and mean relative air humidity was low (5%). The mean CO_2 concentration was 618 ppm, and was below the recommended limit value of 1000 ppm during 97% of measured time. The average concentration of respirable particles in the back of the aircraft (aft galley area) were much higher (67 $\mu g \cdot m^{-3}$) during smoking as compared with non-smoking conditions (4 $\mu g/m^3$) ($p < 0.001$), with maximum values of 430 $\mu g \cdot m^{-3}$ and 12 $\mu g \cdot m^{-3}$ of respirable particles, respectively (**Table IX**).

The noise measurements showed that the average equivalent levels during cruising were 73 dB(A) at flight deck, and 76 dB (A) in forward galley, 74 dB (A) over wing, and 78 dB (A) in aft galley. The frequency distribution of the noise on flight deck, and in aft galley is given in Fig. 1–2.

DISCUSSION

Our results suggest that complaints about the work environment are common among cabin crew, and more common than among office workers. We could identify some possible environmental causes, including environmental tobacco smoke, low relative air humidity, illumination problems, noise, and thermal factors. In addition, the perception of the cabin environment was related to personal factors, including age and atopy, work stress, and lack of influence on working conditions. The study was designed to include all airline crew belonging to the crew base in Stockholm, as well as two representative departments of office workers in Stockholm from the SAS company in Sweden, working outside the airport. The response rate was reasonably high both in cabin crew and office workers (82% and 77%, respectively). Information on both perceptions of cabin environment, and psychosocial work environment, was gathered by the same questionnaire. This could have resulted in recall bias, but since we found different relationships for specific aspects of psychosocial work conditions, it is less likely that observed relationships were due to recall bias. Since different aspects of cabin environment were studied, many statistical tests were made. In most cases, significance levels were below 0.01 or 0.001, suggesting that the results were not due to mass significance.

Complaints on poor indoor air quality were common among aircraft crew, particularly on dry air, stuffy air and static electricity. Many types of complaints were significantly more common among aircraft crew than in office workers from the same company. To our knowledge, there are few other larger studies published on similar types of perceptions of the cabin environment among aircraft crew (20).

As compared with office workers, cabin crew had more complaints of draftiness, too high room temperature, and varying temperature. The complaints of draftiness and varying temperature were similar in all types of staff onboard, but complaints on too high room temperature were frequent only among cabin attendants. The climatological measurements showed that the average room temperature onboard was 22.7°C, but larger variations were registered during cruising conditions (17–27°C). Measurement of air velocity was not performed, but the high rate of air exchange in this type of aircraft could be the cause of these complaints. In addition, asymmetric thermal radiation, e.g., coldness from catering doors at aft galley could also contribute to perception of draft.

Noise in commercial aircraft may occur from different sources, e.g., vibration transmission from the engine through the aircraft body, air-transmitted noise from the engines, and wind velocity noise. Complaints about noise were much more frequent among aircraft crew (41–69%) than in office workers (4%), and most prevalent among flight attendants. Our measurements showed an equivalent noise level during cruising conditions of 73 dB(A) at flight deck and 74–78 dB(A) in the cabin, with most noise in aft galley. The maximum

TABLE IX. CONTINUOUS, 1-MIN IN-FLIGHT MEASURMENTS OF TEMPERATURE, HUMIDITY, CO_2 AND RESPIRABLE PARTICLES, DURING NINE SMOKING FLIGHTS, AND EIGHT NON-SMOKING FLIGHTS.

Type of Factor	N	Mean	(SD)	(min-max)*
Temperature (°C)	7083	22.7	(1.7)	(17.4–27)
Relative air humidity (%)	6570	4.9	(4.0)	(0.9–30)
Carbon dioxide (ppm)	3332	618	(176)	(351–1261)
Respirable particles ($\mu g \cdot m^{-3}$)				
		Before smoking stopped		
	942	67	(61)	(2–430)
		After smoking stopped		
	2296	4	(1.0)	(<1–12)

*Min-max = minimum to maximum values of 1-min values.

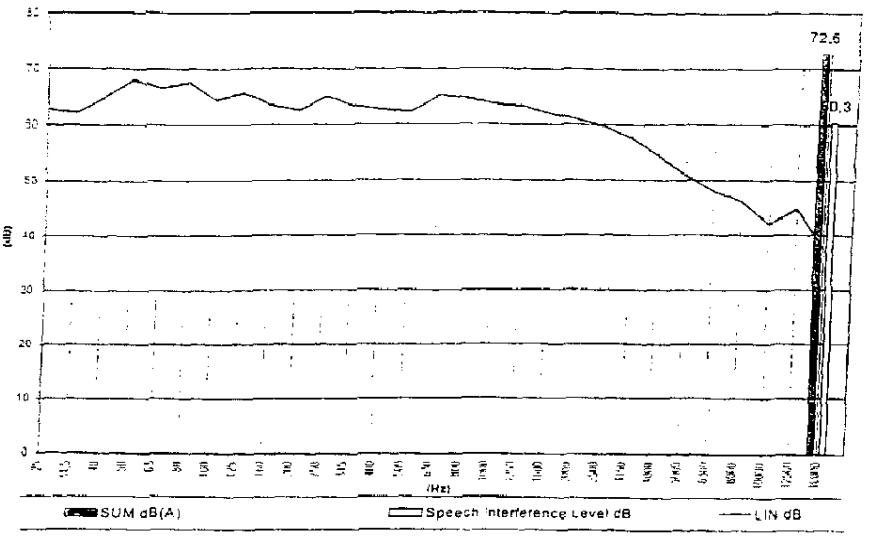

Fig. 1. Noise frequency distribution at flight deck, cruise level 37,000 ft, at flight captain's right ear.

noise frequency in decibels was at 40–60 Hz in the low frequency range, and at 630–800 Hz at speech interference range, both at flight deck and in aft galley.

Many aircraft crew (32–45%), both on flight deck and in the cabin, complained about dust and dirt on surfaces, as compared with 6% of these complaints in office workers. The reason for this is not clear, but could be related to cleaning routines, and the large amount of fleecy materials onboard. Complaints on cabin air quality included air dryness and stuffy air, but was less pronounced for unpleasant odor. The pilots complained less about odor and stuffy air, and the purser complained less about stuffy air and dry air, as compared with flight attendants. Our hygienic measurements showed a very low relative humidity during cruising (typically 3–8% R.H.), and no air humidification was used. At lower relative air humidity, problems with static electricity (tribolectric charging) increases, especially with physical activities, which could explain the high frequency of such complaints (45–50%) in cabin attendants.

In Scandinavia, the indoor relative humidity is usually between 10–35% during wintertime in workplaces (24,16). Controlled experimental field studies have shown that moderate air humidification during winter may decrease the sensation of dryness in offices and hospitals (16,23,24,30), but may increase the sensation of stuffy air (22). In these studies, the workplace of the exposed group achieve air humidification increasing the relative air humidity (R.H.) with about 10% to 30–

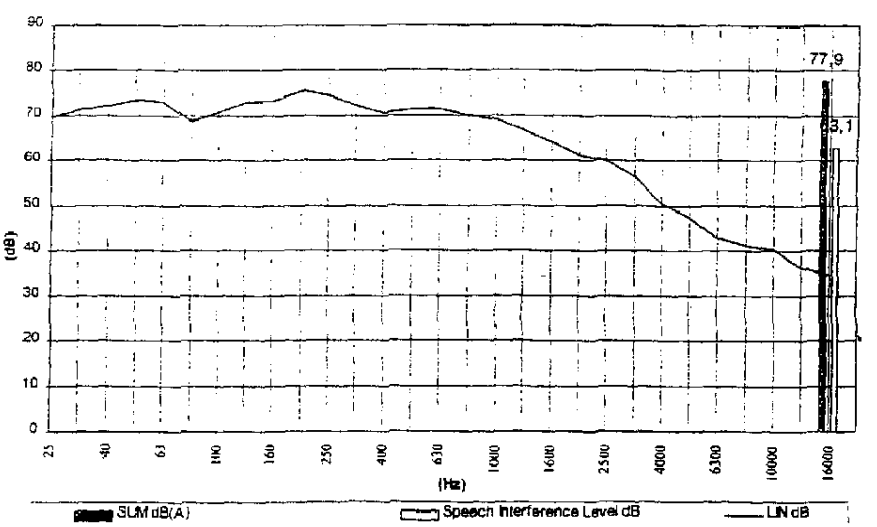

Fig. 2. Noise frequency distribution at aft galley, cruise level 37,000 ft, 160 cm above floor.

40% R.H., while the control unit without humidification had 20–30% R.H. No epidemiological studies on air humidification have been performed at the very low air humidity levels occurring in aircraft. There may also be indirect negative health aspects of air humidification (3,32), due to microbial growth in air-conditioning units (25). Finally, there might be technical difficulties with humidification in aircraft, because of condensation problems and corrosion.

Annoyance from environmental tobacco smoke was common among all categories in the cabin (20–43%), but uncommon on flight deck (4%) and in the office workers (8%). In addition, aircraft crew that had been on a smoking flight the previous week, reported significantly more complaints on dry air and ETS. Our measurements showed a drastic difference of respirable particles in the aft galley (67 v.s. 4 $\mu g \cdot m^{-3}$), when comparing smoking and non-smoking conditions. This illustrates that smoking onboard is a significant source of air pollution.

Personal factors such as female gender, age, smoking habits, and atopy were also related to perception of the cabin environment. The effects were most pronounced for age and atopy. The results agree with other studies showing more complaints about subjective air quality among females (14,29), and subjects with atopy (29,14,32)

We could also demonstrate a relationship between the psychosocial work environment and the perception of the cabin environment. The significance of psychosocial work climate, concerning subjective indoor air quality, has previously been demonstrated in offices, schools, and hospitals (14,16,27,29,32). Stress due to excess of work and lack of influence on working conditions seems to be of particular importance among aircraft crew.

In conclusion, complaints about work environment seems to be more common among aircraft crew than office workers, particularly concerning draftiness, thermal conditions, stuffy air, dry air, static electricity, noise, inadequate illumination, and dust. The large variation of cabin temperature shows a need for more awareness of this problem to achieve a more stable thermal climate. We could identify personal factors of importance, and certain conditions that could be improved, to achieve a better perception of the cabin environment. Important factors were work stress due to excess of work, lack of influence on the working conditions, and environmental tobacco smoke on some longer flights. The hygienic measurements in the cabin, performed only on intercontinental smoking flights, showed that air humidity is very low onboard, and tobacco-smoking onboard leads to significant pollution of respirable particles. Measures to improve cabin air quality could include smoking cessation, improved cleaning, and less use of fleecy materials.

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REFERENCES

1. Andersson K. Epidemical approach to indoor air problems. Indoor Air 1998; Suppl 4:32–9.
2. Andersson K, Stridh G. The use of standardized questionnaires in building-related illness (BRI) and sick building syndrome (SBS) surveys. In: Levy F, Maroni M, eds. NATO/CCMS pilot study on indoor air quality. Oslo: National Institute of Occupational Health, 1992:47–64.
3. Burge S, Hedge A, et al. Sick building syndrome: a study of 4377 office workers. Ann Occup Hyg 1987; 31:493–504.
4. Bischof W. Ozone measurements in jet airliner cabin air. Water, Air, and Soil Pollution 1973; 2:3–14.
5. Crawford WA, Holcomb LC. Environmental tobacco smoke (ETS) in airliners- a health hazard evaluation. Aviat Space Environ Med 1991; 62:580–6.
6. Drake JW, Johnson DE. Measurements of certain environmental tobacco smoke components on long-range flights. Aviat Space Environ Med 1990; 61:531–42.
7. Eatough DJ, Caka FM, Crawford J, et al. Environmental tobacco smoke in commercial aircraft. Atmospheric Environ 1992; 26A: 2211–8.
8. Gebski V, Leung O, McNeil D, Lunn D. SPIDA users manual, version 6, Statistical Computing Laboratory, Eastwood Australia 1992.
9. Hocking MB. Indoor air quality. Recommendation relevant to aircraft passengers cabin. AIHA J 1998; 59:446–54.
10. International Civil Aviation Organisation. Annual report of the Council. Montreal: ICAO, 1993; Doc 9922.
11. Mattson ME, et al. Passive smoking on commercial airline flights. JAMA 1989; 261:867–72.
12. Nadga NL, Koontz MD, Konheim AG, Hammond SK. Measurement of cabin air quality aboard commercial airliners. Atmospheric Environ 1992; 26A:2203–10.
13. Nastrom GD, Holdeman JD, Perkins PJ. Measurements of cabin and ambient ozone on B747 airplanes. J Aircraft 1980; 17:246–9.
14. Norbäck D. Subjective indoor air quality in schools - the influence of high room temperature, carpeting, fleecy wall materials and volatile organic compounds (VOC). Indoor Air 1995; 5:237–46.
15. Norbäck D. Sick building syndrome and building-related illness. In: Brune D, Gerhardsson G, Crockford G, d'Auria D, eds. The workplace. Vol.1. Fundamentals of health, safety and welfare. Geneva: International Occupational Safety and Health Information Centre (CIS), International Labour Office (ILO), and Oslo: Scandinavian Science Publisher, 1997; 501–32.
16. Nordström K, Norbäck D, Akselsson R. Subjective indoor air quality in hospitals - the influence of building age, ventilation flow, and personal factors. Indoor Environ 1995; 4:37–44.
17. Nordström K, Norbäck D, Akselsson R. Effect of air humidification on the sick building syndrome and perceived indoor air quality in hospitals: a four month longitudial study. Occup Environ Med 1994; 51:683–8.
18. Oldaker GB III, Condrad FC. Estimation of effect of environmental tobacco smoke on air quality within passenger cabins of commercial aircraft. Environ Sci Tech 1987; 21:994–9.
19. Owe JO. Air transportation In: Brune D, Gerhardsson G, Crockford GW, Norbäck D, eds. Major industries and occupations. Geneva: International Labour Office 1997; 107–25.
20. Pierce WM, Janczewski JN, Roethlisberger B, Janczewski MG. Air quality on commercial aircraft. ASHRAE J 1999; 41:26–34.
21. Rayman RB. Passenger safety, health and comfort: A review. Aviation, Space, and Environmental medicine 1997; 68:432–440.
22. Reinikainen LM, Aunela-Tapola L, Jaakkola JJK. Humidification and perceived indoor air quality in the office environment. Occupational and Environmental Medicine 1997; 54:322–327.
23. Reinikainen LM, Jaakkola JJK, Heinonen OP. The effect of air humidification on different symptoms in office workers -an epidemiologic study. Environment International 1991; 17:243–50.
24. Reinikainen LM, Jaakkola JJK Seppänen O. The effect of air humidification on Symptoms and Perception of Indoor Air Quality in Office Workers: A Six-Period Cross-Over Trial. Arch of Environmental Health 1992; Vol:47:No 1.
25. Schata M, Jorde W. Allergies to molds caused by fungal spores in air conditioning equipment. Environment International 1989; Vol 15:177–179.

26. Skov P, Valbjorn O, et al. The sick building syndrome in the office environment: The Danish Town Hall study. Environ Int1987; 13:339–49.
27. Smedje G, Norbäck D, Edling C. Subjective indoor air quality in schools in relation to exposure. Indoor Air 1997; 7:143–150.
28. Stenberg B, Hansson Mild K, Sandström M, et al. A prevalence study of the sick building syndrome (SBS) and facial skin symptoms in office workers.Indoor Air 1993; 3:71–81.
29. Wallace LA, Nelson CJ, Highsmith R, Dunteman G. Association of personal and workplace characteristics with health, comfort and odor: A survey of 3948 office workers in three buildings. Indoor Air 1993; 3:193–205.
30. Wyon D. Sick buildings and the experimental approach. Environ Tech 1992; 13:313–22.
31. Wålinder R, Norbäck D, et al. Nasal patency and biomarkers in nasal lavage- the significance of air exchange rate and type of ventilation in schools. Int Arch Occup Environ Health 1998; 71:479–486.
32. Zweers T, Preller L, Brunekreef B, Boleij JSM. Health and indoor climate complaints of 7043 office workers in 61 buildings in the Netherlands. Indoor Air 1992; 2:127–136.